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A SPECTROSCOPIC INVESTIGATION OF COMBUSTION-DRIVEN IMPLOSIONS.(U)  
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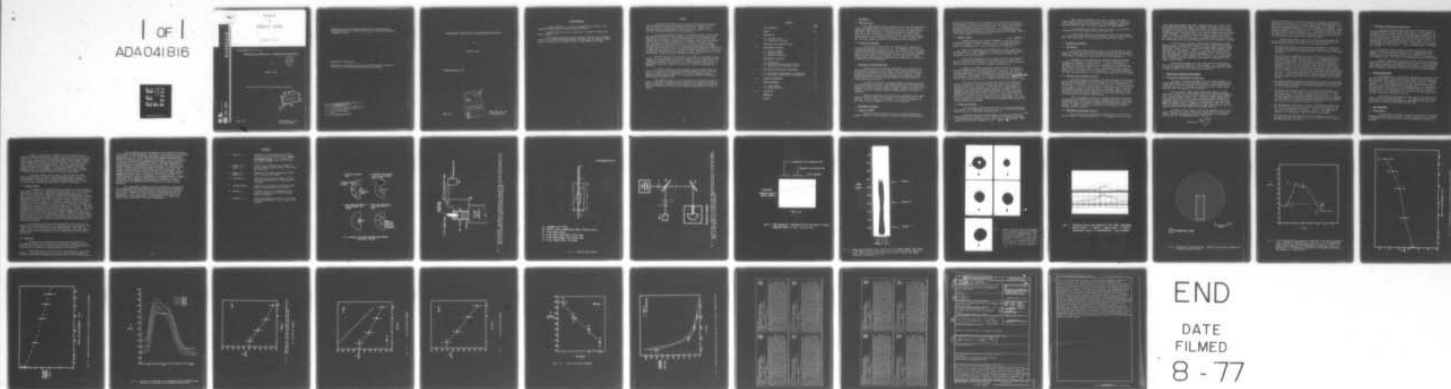
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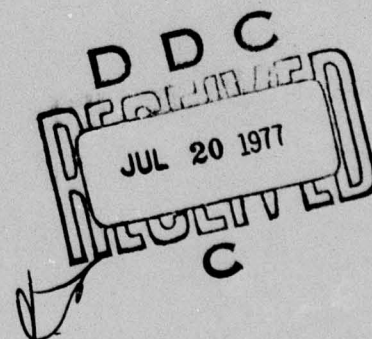
A SPECTROSCOPIC INVESTIGATION OF COMBUSTION-DRIVEN IMPLOSIONS

by

(12)

Randy A. Roig

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A SPECTROSCOPIC INVESTIGATION OF COMBUSTION-DRIVEN IMPLOSIONS

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Randy A. Roig

Submitted January, 1977

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### Summary

Time and spatially-resolved spectroscopic studies have been made of imploding shock waves in a 20-cm diameter hemispherical chamber filled with  $2H_2 + O_2$  mixtures at high initial pressures (7-56 atm). Changes in the initiation system (an exploding wire) have improved the precision of the focus and the reproducibility of the implosion pulse.

By using the blackbody character of the plasma radiation above  $3000\text{\AA}$ , the temperature structure of the implosion was determined both temporally and spatially as a function of initial filling pressure. It was found that peak temperatures (4500-5100K), averaged over a rectangular area 3 mm x 9 mm centred near the origin, increased monotonically as a function of filling pressure, while implosion pulse durations (8.5-4.0  $\mu\text{s}$ ) underwent a monotonic decrease. The implosion pulse, normalized by the duration and temperature rise, appeared to have a nearly universal shape. The spatial gradient of temperature  $[dT/d(\log R)]$ , averaged over the implosion pulse duration, increased monotonically as a function of initial filling pressure. All temperature results (peak temperature, duration, and gradient) averaged 15-20% below theoretical predictions.

The time history of the pressure at the origin for an initial filling pressure of 7 atm, averaged over a 6.3 mm diameter circle, was measured by using a high-pressure piezoelectric transducer. The peak pressure, about 8 kbar, is 15-20% below theoretical predictions. This result represents the first direct measurement of pressure achieved at the focus of a gas-driven hemispherical implosion.

To check the effect of window conduction upon the plasma located at the focus, the window was recessed 3 mm from the geometric centre of the hemisphere. No change in peak temperature was observed, although as might be expected from the change in position of the reflecting surface, the implosion pulse duration decreased by 18%.

The presence of debris (such as that left by the exploding wire) was found to lower both the implosion pulse duration and the temperature remaining after the implosion. No effect on peak temperature was measured, even when the effect was enhanced by the addition of an easily vaporized impurity (silicon grease).

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## 1. INTRODUCTION

### 1.1 Historical Note

The UTIAS implosion device has been an active area of research since it was conceived by Glass in the early 1960's (Ref. 1). The high pressure/temperature conditions that are created at the focus of the implosion have been used to drive projectiles at hypervelocity, generate high-velocity shock waves, and, most recently, to create diamonds. An earlier spectroscopic study (Ref. 2) suffered from difficulties arising from poor focusing and centering. Owing to an improved initiation technique, further insight into the actual plasma conditions at the focus has now been obtained.

### 1.2 Principle of Operation

The principle of operation of the UTIAS implosion chamber can be understood by referring to Fig. 1 (Ref. 3). The hemisphere is filled with a combustible hydrogen-oxygen mixture ( $2H_2 + O_2$ ) at high pressure (7-56 atm). The gas is initiated by exploding a fine wire at the origin of the hemisphere which initiates a steady outgoing detonation wave. Upon reflection from the liner, the wave implodes upon the origin. Here the wave reflects again, leaving behind a high-pressure, high-temperature plasma region. This region is the object of the investigation.

## 2. OBJECTIVES OF SPECTROSCOPIC WORK

Previous work (Ref. 2) on the spectroscopy of low pressure ( $\leq 21$  atm) gas-driven implosions suffered from a lack of reproducibility and of precisely focused implosions in the chamber. With several recent changes in the initiation technique, off-centred implosions are no longer a serious problem and another low-initial-pressure study of the temperature history of the implosion was warranted. The investigation was also extended to higher initial filling pressures.

An effort was also made to measure simultaneous pressure histories by utilizing optical techniques. This attempt failed due to the black-body nature of the radiation in the visible part of the spectrum and unknown cross-sections in the far ultraviolet region ( $\approx 2000\text{\AA}$ ). Instead, a piezoelectric transducer was used to measure the pressure-time history of low-pressure implosions.

Additional photographic observations were undertaken with an image converter camera to improve our knowledge of the focusing processes in the implosion. Several questions still remain as to the structural nature of the plasma during and immediately after the actual implosion.

## 3. EXPERIMENTAL EQUIPMENT

### 3.1 Implosion Chamber

The MK III Implosion Chamber consists of a 20-cm diameter hemispherical chamber in a steel block. The top plate containing the gas inlet,

the ignition feedthrough, and the observation port was secured to the back plate by means of thirty-two 3.81-cm bolts. The observation window was either a 2.5-cm diameter by 0.64-cm thick quartz disk or a 2.5-cm by 1.27-cm thick UVT plexiglass square glued into a steel barrel. For high-pressure runs, additional windows and baffles were necessary to stop the high-pressure gas from escaping into the surrounding room and causing structural damage. Details of the MK III chamber are available in Ref. 4.

### 3.2 Ignition System

Previous problems with off-centre implosions in gas runs led to an effort to improve the ignition system. As before, an exploding wire was placed at the geometric centre of the hemisphere. To increase the aspect ratio of the exploding wire, several new approaches were introduced.

First, the exploding wire was changed from a 10-mil copper wire to a 5-mil nickel wire. This increased the resistance of the exploding element by a factor of 14. Nickel was chosen for its mechanical strength, high resistance, and ease of soldering.

Second, the transmission line was changed from RG-8 (52 $\Omega$  impedance) to a low-inductance (16 $\Omega$  impedance) cable (provided by M. M. Kekez of the National Research Council of Canada). Besides reducing the circuit resistance, the lower inductance decreased the discharge time significantly.

Finally, the thyatron/capacitive discharge system was replaced by a spark gap/capacitive discharge system (shown in Fig. 2). The spark gap which is constructed from two brass electrodes, a plexiglass tube, and an automobile spark plug, is first dehumidified by flowing compressed nitrogen. The capacitor is then charged to 20 kV and a 5 kV trigger pulse to the spark plug initiates the discharge. It is estimated that the power dissipated in the wire was increased by a factor of 70-100 over the previous ignition system.

Since the consistency of the implosion pulse duration apparently depends on the design of the exploding wire (see Section 7.2), the details are given in Fig. 3 for reference. A 1-mm nickel wire is soldered to two pieces of No. 20 solid copper wire. The longer piece, 67-mm in length, is shielded by No. 20 teflon tubing starting 3-mm from the nickel wire. This assembly is glued with epoxy (Lepage's 5-min epoxy) to a 15-mm x 10-mm polyethylene sheet (0.25-mm thick) at two locations: 3-mm and 5-mm away from the nickel wire along the longer and shorter wires, respectively. With the nickel wire positioned over the geometric centre of the hemisphere, the copper wires are soldered into position. This holds the assembly firmly in place; no further adhesives are necessary.

### 3.3 Diagnostic Equipment

All spectroscopic measurements were made with a Hilger medium quartz spectrograph. For photographic work, Kodak type 1-0, 1-F and Tri-X Pan plates were used because of their high sensitivity (Ref. 5).

Preliminary photoelectric measurements were made with an EMI 9558 photomultiplier (S-20 cathode). Later, a Hilger E751 "Strassheim" attachment to the spectrograph enabled simultaneous measurements at 6 wavelengths. Time response of the system was typically 0.2  $\mu$ s.

Time-resolved photographic work was done using the TRW Model 1D image converter camera in conjunction with either a framing or streak unit. In the framing mode up to five "snapshots" of the imploding and exploding shock wave could be taken, allowing an examination of radial symmetry.

The streak mode, when used in conjunction with a slit, recorded a continuous view of the radial position of the shock wave.

Pressure measurements at the origin at an initial filling pressure of 7 atm were made with a PCB Piezotronics 119M08 transducer. This instrument had a rise time of about 1  $\mu$ s and a calibrated range of 0-8,200 atm.

#### 4. PRELIMINARY DIAGNOSTICS

##### 4.1 Introduction

As in the previous experiments (Ref. 2), it was advisable to undertake a preliminary investigation of the general characteristics of gas-driven implosions. The diagnostics used were time-resolved photoelectric recordings of the emitted radiation and framing camera views of the implosion.

Generally, each run consisted of viewing the implosion generated in a  $2H_2 + O_2$  mixture at a filling pressure of 7 atm. A schematic of the experimental arrangement is shown in Fig. 4. To protect the diagnostic equipment, the implosion is observed via an expendable front-surface mirror,  $M_1$ , located 10 cm from the chamber barrel. A beam splitter ( $M_2$ ) divides the light, sending 30% through lens  $L_1$ , to the image converter camera and 40% through lens  $L_2$  and filter F to the photomultiplier. In the final experiment, the filter and photomultiplier were replaced by the medium quartz spectrograph.

##### 4.2 Time-Resolved Photoelectric Results

For future timing considerations, several experiments were performed with an EMI 9558 photomultiplier monitoring the radiation emitted by the source. Because this photomultiplier has an S-20 cathode, it is an ideal monitor for all radiation, from the near ultraviolet to the infra-red. A typical recording, shown in Fig. 5, was taken without a filter. The initial region is marred by electromagnetic pickup from the exploding wire discharge. After a time, the interference disappears and the radiation from the plasma dominates. As the implosion focuses, the radiation increases to a peak, then falls off quickly to a value below the initially combusted gases.

Later, recordings were made with a Wratten series VI No. XI filter (Green) and a Corning "Blue-glass" filter. These had the effect of centering the photomultiplier response around 5000Å and 4200Å respectively. With these filters, the response is limited to higher-temperature/greater-convergence regions. As might be expected, the duration of the implosion as viewed through the filter decreases.

##### 4.3 Time-Resolved Photographic Results

The velocity of the incoming and outgoing shock wave can be determined by taking a streak photograph (Fig. 6). The imploding shock wave forms

a high temperature hemispherical shell around the origin (1.5-3.4  $\mu$ s) which, when viewed from the front, appears as a doughnut (see Frame 1, Fig. 7). As the implosion approaches the origin, the intensity as recorded by the camera increases (3.5-4.0  $\mu$ s), then decreases due to its shrinking size (4.0-4.8  $\mu$ s). The minimum apparent intensity occurs at the greatest collapse when the affected volume is smallest. The shock reflects and explodes (4.8-6.5  $\mu$ s) at about an eighth of its imploding velocity. This is in general agreement with theory. For a plane wave, the ratio of outgoing to incoming velocity is about one third for strong shock waves. The spherical geometry serves to accentuate the effect.

A series of five sequential framing camera photographs were taken, spaced by 1-2  $\mu$ s. Exposures were limited to 50-100 ns, during which time the plasma parameters were predicted to have only slight changes. Figure 7 shows the results. Frame 1 (3.2  $\mu$ s) confirms the "doughnut-like" appearance of the shock wave during convergence. Frame 2 (4.5  $\mu$ s) shows the wave just before final collapse. The luminous area then gradually cools and expands to the size (19 mm diameter) of the viewing window (Frames 3-5). It should be noted that the slight outer radial asymmetry shown in Frames 1 and 5 is partially due to reflections from the barrel wall and defects in the phosphor of the image converter camera.

From these photographs, one can conclude that the incoming shock wave is stable and fairly symmetric at this pressure. Also, the window does not appear to break during the shock. Thus, photoelectric diagnostics (which assume both symmetry and window integrity) are justified.

## 5. TIME-RESOLVED TEMPERATURE MEASUREMENTS

### 5.1 Photoelectric Measurements of Temperature

The Hilger Strassheim attachment to the spectrograph enabled up to 6 wavelength regions to be monitored simultaneously. After calibration, the signals could be converted to relative intensities and interpreted in terms of the expected (Ref. 2) blackbody-like emission spectrum. Typical photomultiplier (PM) recordings are shown in Fig. 8.

The wavelengths, 3660 $\text{\AA}$ , 3800 $\text{\AA}$ , 4060 $\text{\AA}$ , 4200 $\text{\AA}$ , 4950 $\text{\AA}$ , and 5770 $\text{\AA}$ , were chosen for their ease of setting and sensitivity within the temperature range. The calibration was done in the conventional manner using a chopper and a tungsten filament standard lamp. Calibration signals differed by no more than a factor of 3 from the expected peak experimental intensities to minimize nonlinear response problems. For temperatures in the range 4500-5000K, the expected error per experiment (67% confidence limits) is  $\pm 110$ K. The error increases when the temperature is either higher or lower than that range, primarily due to the shape of the blackbody function.

It should be noted, however, that the PM recordings do not give a "true" temperature due to the temperature gradients that are present in the plasma. Instead, the temperature reflects an averaging over the image at the entrance slit of the photomultiplier. That is,

$$I_{(\text{measured})} = \frac{\int_{\text{slit}} I(x,y) dA}{\int_{\text{slit}} dA}$$

Since the variation of the blackbody function with temperature [approximately  $\exp(-hc/\lambda kT)$ ] is different for every wavelength, each average intensity will represent a slightly different "brightness temperature" (the temperature which would give the measured intensity if the observed image was isothermal). Thus, temperature gradients  $[dT/d(\log R)]$  can be both detected and estimated. Apparently the deviation was not detected in Ref. 2, unless this is the reason for the large quoted ( $\pm 500K$ ) experimental error. The area over which the average was taken is shown in Fig. 9. A direct comparison of the results with Ref. 2 was not possible as the integration area was not specified.

Keeping these remarks in mind, the following general comments can be made about the present results (Fig. 10, the results of a typical 7 atm initial-pressure experiment, is used for illustrative purposes):

1. The ambient temperature  $T_A$  is virtually constant about 20  $\mu s$  after detonation and shows a definite increase with filling pressure. It shows a "scatter" of 200-400K for any given pressure. The value of  $T_A$  is typically 3000-3500K.
2. The average "peak" temperature  $T_p$  increases directly as a function of filling pressure. Unlike the work of Ref. 2, these temperatures proved to be fairly reproducible and is a reflection of the improved characteristics of the implosions. The graph of  $T_p$  as a function of filling pressure is shown in Fig. 10. Each point represents the average of four experiments, except for the 56 atm point which for safety reasons was limited to one run. The error estimates (67% confidence limits) reflect both the estimated error in the individual experiment and the averaging process. For this reason, the error in the 56 atm point has been increased to  $\pm 150K$ . The only readily available theoretical implosion calculation is from Ref. 6. The result, 5500K for a 14 atm filling pressure (as averaged over the appropriate area by the present author), appears to be too high by 850K.
3. The spatial gradient of temperature  $[dT/d(\log R)]$  reaches a maximum during the early peak of the implosion, then decreases rapidly to below the level of detectability (800K/cm) for 7 atm filling pressure to about 1600K/cm for 56 atm filling pressure.
4. The plasma pluse duration  $\tau$  (defined as the width of the implosion in time between  $[T_A + 100K]$  heights - see Fig. 10) decreases as a function of filling pressure. The trend is shown graphically in Fig. 12. The data points represent the same experimental runs as in Fig. 11. Although a direct comparison is difficult, numerical calculations (Ref. 6) indicate that the durations are about 30-50% shorter than predicted analytically. This subject will be discussed further in Section 7.2.
5. The implosion shape with respect to time is essentially the same for all filling pressures, normalized by the duration in the time direction and  $(T_p - T_A)$  in the temperature direction. A graph of the temperature as a function of normalized time is shown in Fig. 13. Each shape is an average of four experiments, except for the 56 atm experiment.
6. The temperature  $T_p$  persisting after the first implosion is "over" is typically 200-400K lower than  $T_A$ . This is in contrast to the calculated 200-400K temperature rise (Ref. 6).

## 5.2 Photographic Measurements of Temperature

"Time-resolved" photographic measurements were made by using a rotating disk shutter similar to that used in Ref. 2. In this manner, one can obtain spatially-resolved images of the temperature distribution. Unfortunately, due to low efficiency in the optical imaging system, a choice had to be made between integration time and resolution. For example, for a 7-atm filling-pressure experiment, one could not integrate over the approximately 1  $\mu$ sec of maximum convergence (shown in Figs. 6 and 7) unless the resolution was limited to about 4.5-mm. A compromise was to integrate over the implosion pulse duration  $\tau$ . This, in general, gives a resolution of  $\pm 0.25$ -mm.

The results of this analysis are shown in Fig. 14(a-d). The temperature points represent the average of 2-4 experiments per filling pressure. The nearly universal temperature error estimates of  $\pm 150$ K reflect the error per experiment ( $\pm 200$ K), the problems of centering, and the averaging process. The radial error estimates arise from the resolution.

Comparison data (Ref. 6) are shown on the 14 atm filling pressure graph (Fig. 14b). Unlike the experimental points which represent the temperature gradient averaged over the implosion pulse duration  $\tau$ , the theoretical points represent the predicted temperatures and gradient at peak convergence. Thus, the agreement between the two results (10-15%) is fairly reasonable.

## 6. PRESSURE MEASUREMENTS

The availability of a high-pressure piezoelectric transducer allowed the first measurement of the actual pressures achieved during an implosion. The transducer, which averaged over a 6.3 mm diameter circle, was protected from the heat of the implosion by two layers of electrical tape. The time response, 1  $\mu$ sec, and ringing frequency, 500 kHz, provided difficulties as both were close to the half-width of the pressure pulse. For this reason, it was not possible to follow the fast rise to maximum pressure. However, by averaging over seven experiments (initial pressure 7 atm), an estimate of the peak pressure and a measurement of the decay curve of the pressure pulse was made. The results are shown in Fig. 15.

A more detailed investigation of the pressure time-history at the origin is now nearing completion (Ref. 7). It is expected that this study will provide more accurate measurements of peak pressure, rise time, and decay rates for initial filling pressures of 2-7 atm.

## 7. OTHER EXPERIMENTS

### 7.1 Window Effects

It is important to determine the effect of the window on the plasma. Although conduction calculations (Ref. 2) seem to indicate that this effect is negligible under present conditions, further experimental evidence is desirable.

Ideally, one would like to remove the window (or recess it) and observe the same implosion process. However, this is a difficult task - the presence of a recess creates new phenomena through diffraction and rarefaction waves. Also, the removal of the reflecting surface from the geometric centre of the hemisphere is certain to modify the implosion, if not before maximum focus, then in the explosion that follows. With these problems in mind, several experiments were attempted with the window recessed 3 mm from the geometric centre of the hemisphere. No change was observed in the peak temperature ( $T_p$ ), but the implosion pulse duration ( $\tau$ ) decreased, as might be expected from the change in position of the reflecting surface.

As further evidence, one can point to the fact that the three types of windows that were used in normal experiments (glass, quartz, and UVT plexiglass) yielded exactly the same peak temperature and implosion pulse duration. Although these results are far from definitive, they seem to indicate that the window has only a minor effect on the plasma.

## 7.2 Impurity Effects

It is important to check the effect of impurities from the exploding wire (copper, nickel, lead, polyethylene, teflon, epoxy, etc.) on the implosion temperature and duration. Since none of these materials has spectral lines that could be easily viewed ( $2000\text{\AA} \leq \lambda \leq 2500\text{\AA}$ ) at these temperatures, a thin layer of silicon grease was added. The results were quite significant; although approximately the same peak temperature  $T_p$  was reached, the implosion pulse duration  $\tau$  decreased by about  $1.5 \mu\text{s}$  (18%) for a 7 atm initial filling pressure. Several very weak and broadened Si I transitions appeared, rising to a peak intensity just as the temperature started to fall. In addition, the temperature remaining after the implosion,  $T_b$ , was about 500K lower than normal. This seems to explain two conflicts with the theoretical predictions: the lower temperature remaining after the implosion and the lower implosion pulse duration. Since the detonation wave leaves behind only a gas of moderate temperature (3000K) and pressure (30-100 atm), little vaporization occurs. However, the higher temperatures and pressures that occur during the maximum focus ablate any easily vaporized substance that may be present. The resultant energy losses from the latent heats of vaporization and dissociation cause a lower final temperature and a shorter pulse duration.

As a further test, the amount of polyethylene, solder and epoxy was doubled for several exploding wires. The effect was much less dramatic:  $0.75 \mu\text{s}$  decrease in duration (9%) and a final temperature about 150K lower than normal. Still, these decreases do verify our hypothesis: the lower implosion pulse durations and final temperatures arise from the debris left by the exploding wire.

## 8. CONCLUSIONS

The changes in the initiation system have greatly improved the precision and quality of the focusing of the implosion. However, it has now been shown that the debris from the exploding wire lowers the implosion pulse duration and the temperature remaining after the first implosion.

Time-resolved pressure histories have been recorded for low initial pressure (7 atm) implosions for the first time. The measurements appear to be about 15-20% below the analytical predictions (Ref. 6) on an absolute scale.

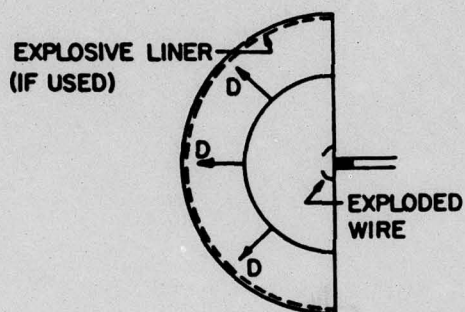
Time and spatially-resolved temperature histories have been measured as a function of filling pressure. The results, also 15-20% below the numerical results (Ref. 6), show considerable improvement in precision from previous measurements (Ref. 2). It was found that the normalized temperature-time history of the implosions has a nearly universal shape. It is not clear what is the exact cause for the 15-20% difference in absolute scale between the experimental and predicted temperature results. Non-ideal symmetry of the imploding wave and its extension into the reflecting wave, wall effects, or undetected impurity effects are all likely candidates. To isolate any one of these variables would be difficult and would require much work. For example, the exploding wire could be replaced with a laser spark. However, the laser spark would have to dissipate a large amount of energy while not damaging the entrance window, a demanding, if not impossible task. The easiest variable to isolate is the structure of the imploding wave. Perhaps a high-speed, high-resolution examination of the implosion would help to clarify the role of symmetry in the limitations of the focus. This is undoubtedly also an important aspect of successful laser fusion through implosions.

The experimental techniques that were developed for this work can now be carried over into the investigation of explosive-driven implosions. It is expected that the deviations from theoretical predictions observed in gas runs will be magnified; 30-50% reduction in performance would not be unreasonable. Still, one can expect pressures greater than  $10^5$  atm and temperatures in the 50,000K range. The measurements still remain to be done and will be the subject of a future investigation.

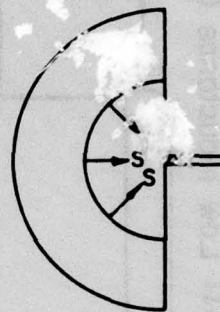
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1. OUTGOING DETONATION WAVE



2. DETONATION WAVE REFLECTS AS SHOCK WAVE (INITIATES LINER, IF USED)



3. MAIN SHOCK CONVERGES ON ORIGIN, BECOMING VERY STRONG



4. SHOCK WAVE REFLECTS ON ORIGIN AND MOVES OUT AGAIN

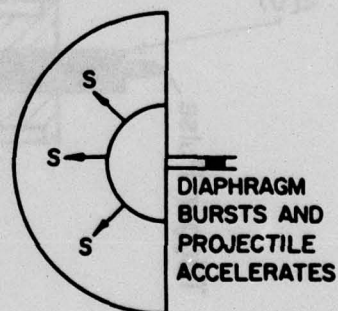


FIG. 1 SCHEMATIC OF IMPLOSION CHAMBER WAVE DYNAMICS  
(REPRODUCED FROM REF. 1)

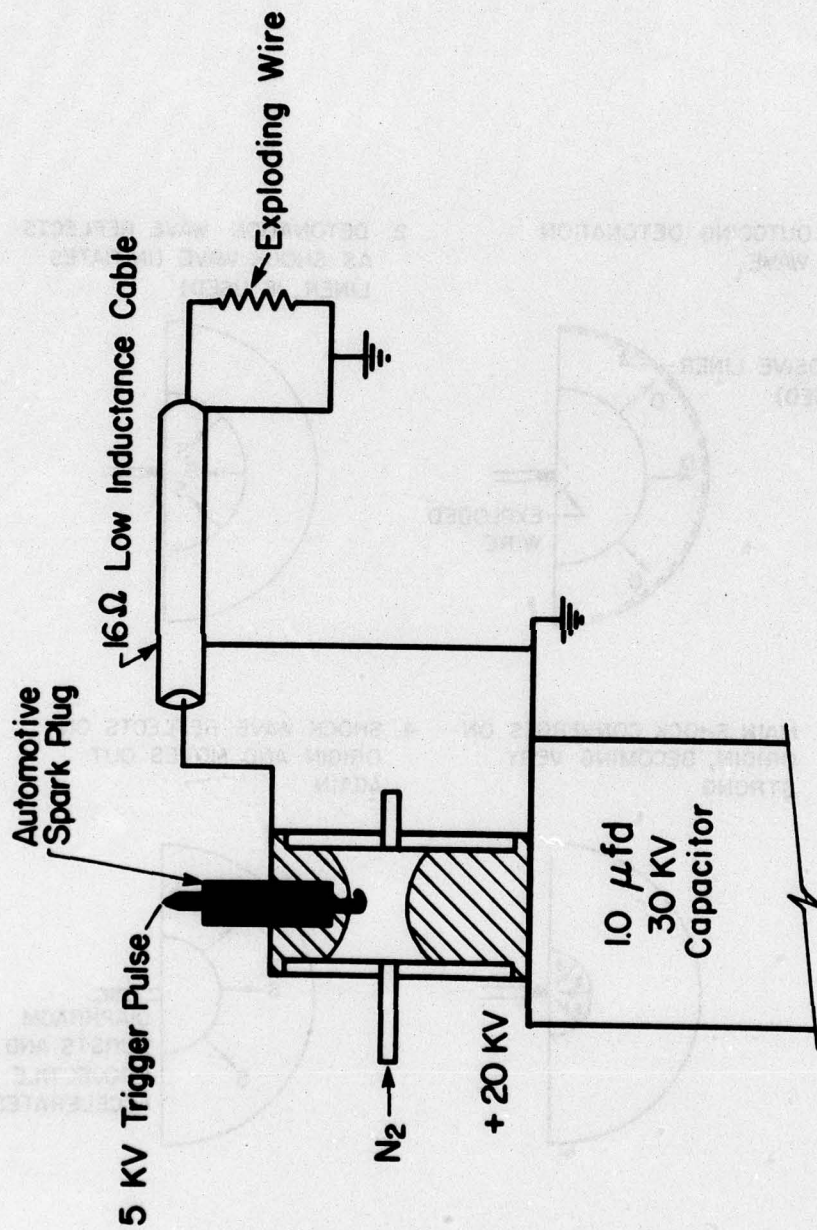
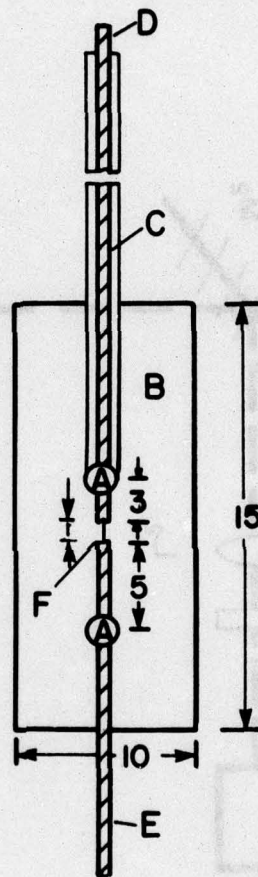


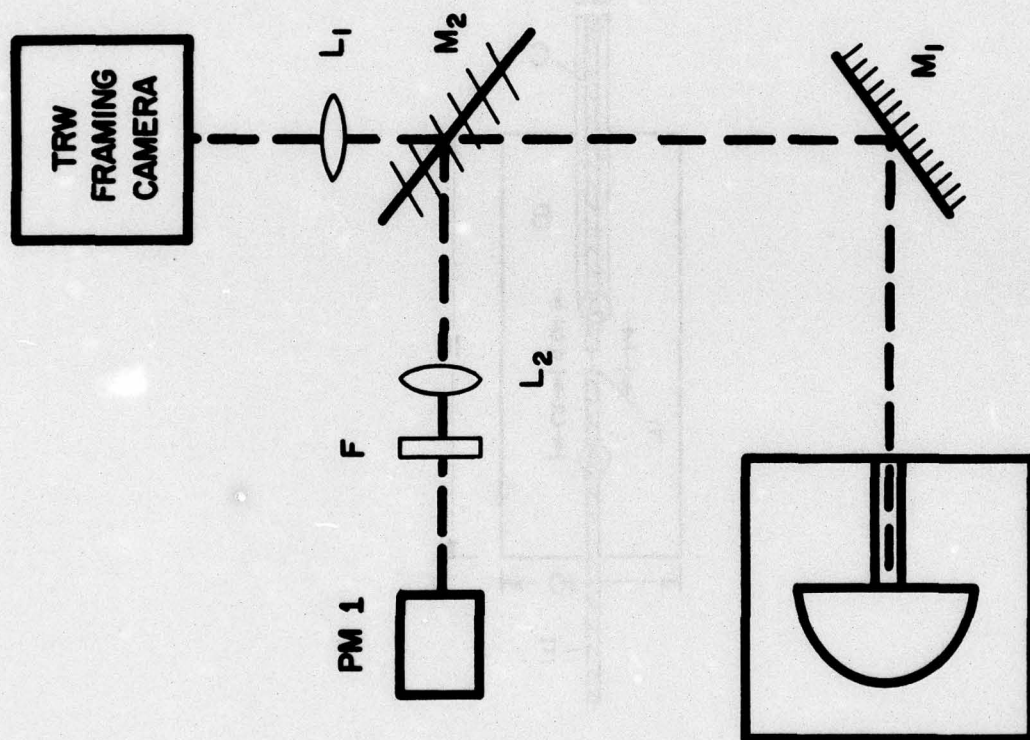
FIG. 2. IGNITION ASSEMBLY. THE SPARK GAP, CONSISTING OF 2 BRASS ELECTRODES IN A PLEXIGLASS TUBE WITH A SPARK PLUG TRIGGER, IS DEHUMIDIFIED BY FLOWING COMPRESSED NITROGEN. THE CAPACITOR IS THEN CHARGED TO 20 kV AND A 5 kV TRIGGER PULSE TO THE SPARK PLUG INITIATES THE DISCHARGE.

All Dimensions in mm.



- A - Lpages 5 min. Epoxy.
- B - 15 mm x 10 mm Polyethylene Sheet (0.25 mm thick).
- C - # 20 Teflon Tubing.
- D - # 20 Solid Copper Wire, 67 mm long.
- E - # 20 Solid Copper Wire, 25 mm long.
- F - 5 mil. Nickel Wire, 1 mm long.

FIG. 3. EXPLODING WIRE ASSEMBLY.



# IMPLOSION CHAMBER

FIG. 4. THE IMPLOSION IS VIEWED BY AN EXPENDABLE FRONT-SURFACE MIRROR  $M_1$  LOCATED 10 CM FROM THE CHAMBER BARREL. A BEAM SPLITTER  $M_2$  DIVIDES THE LIGHT, SENDING 30% THROUGH LENS  $L_1$  TO THE IMAGE CONVERTER CAMERA AND 40% THROUGH LENS  $L_2$  TO THE SPECTROGRAPH.

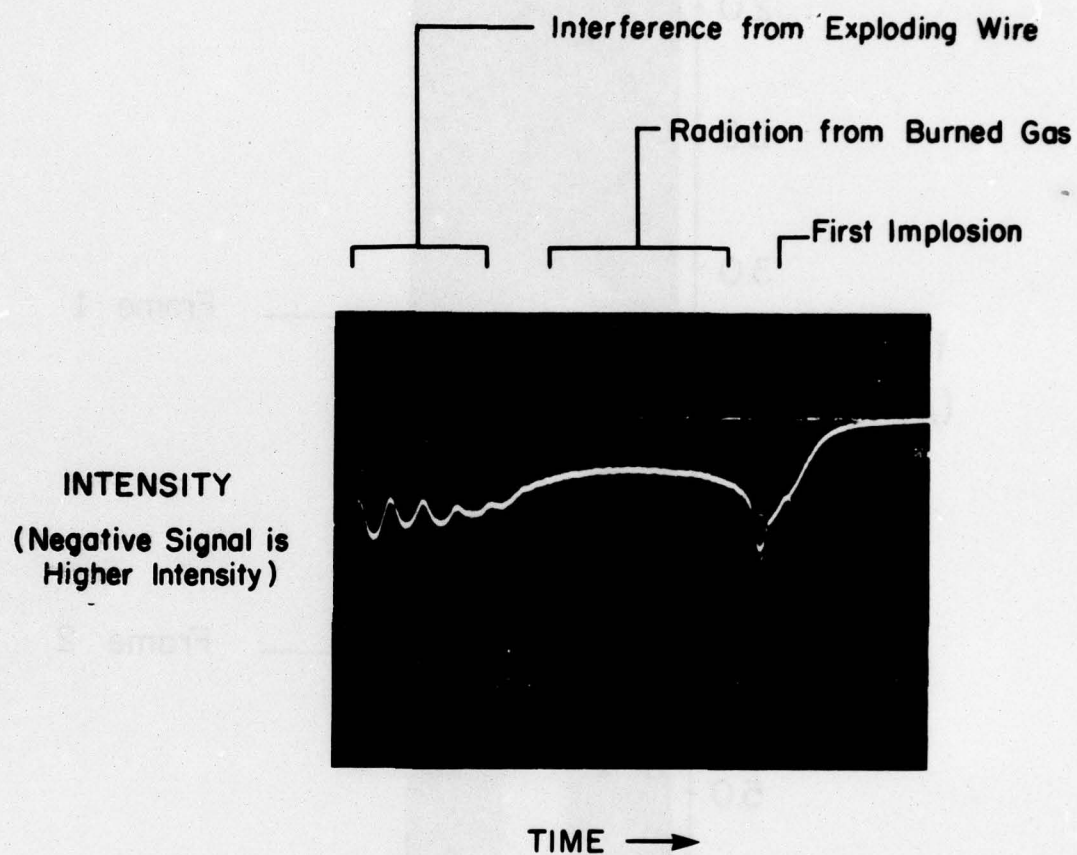


FIG. 5 TIME-RESOLVED PHOTOMULTIPLIER RECORDS OF VISIBLE EMISSION FROM A 14 atm  $2\text{H}_2 + \text{O}_2$  RUN

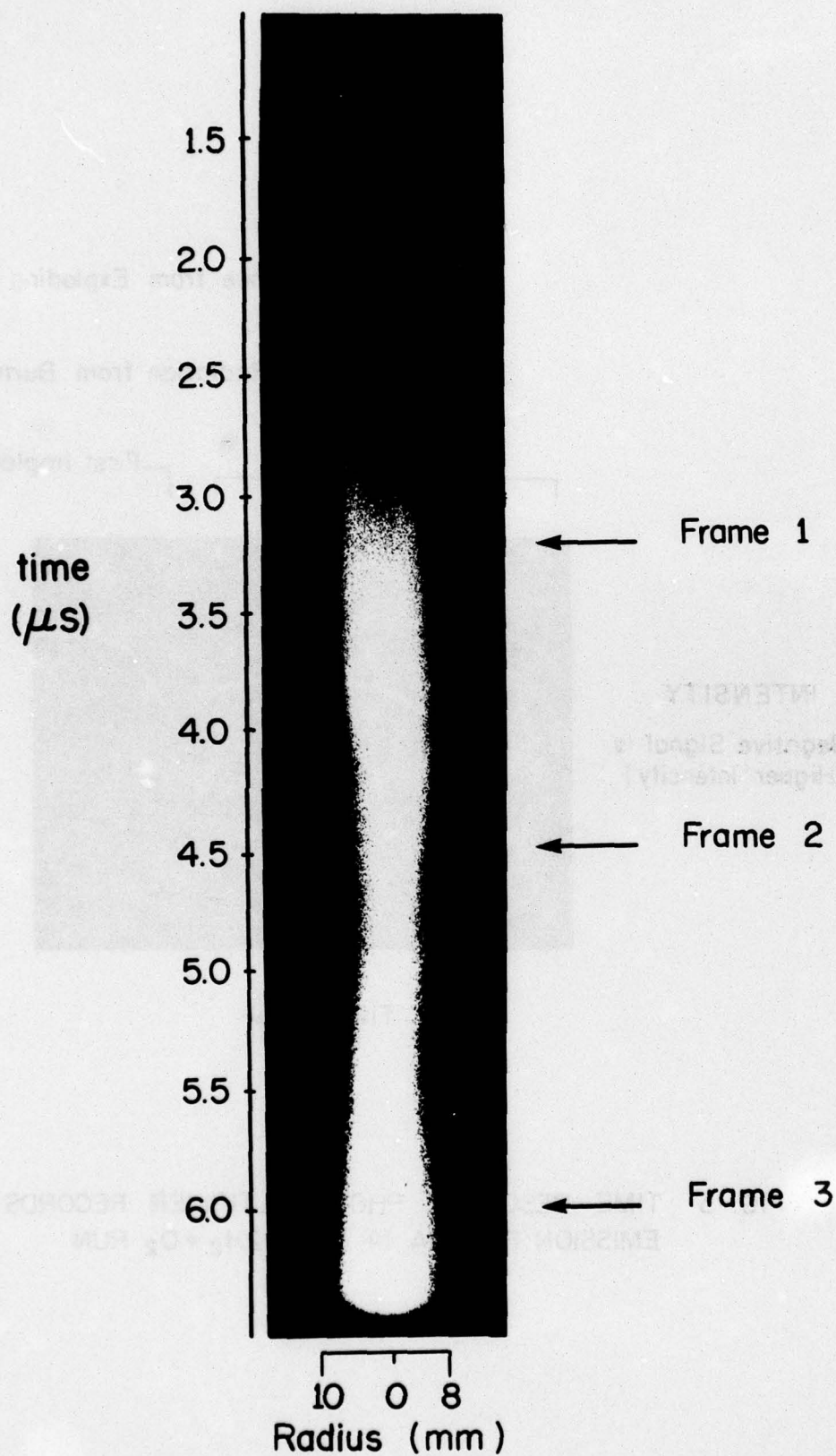


FIG. 6. STREAK CAMERA RECORDING TAKEN THROUGH THE 19 MM DIAMETER WINDOW AT THE WINDOW AT THE ORIGIN OF THE IMPLOSION CHAMBER DURING A RUN AT AN INITIAL PRESSURE OF 7 ATM. THE TIME SCALE CORRESPONDS TO THAT OF FIGS 7 AND 10. THE FRAMES CORRESPOND TO THOSE SHOWN IN FIG. 7.

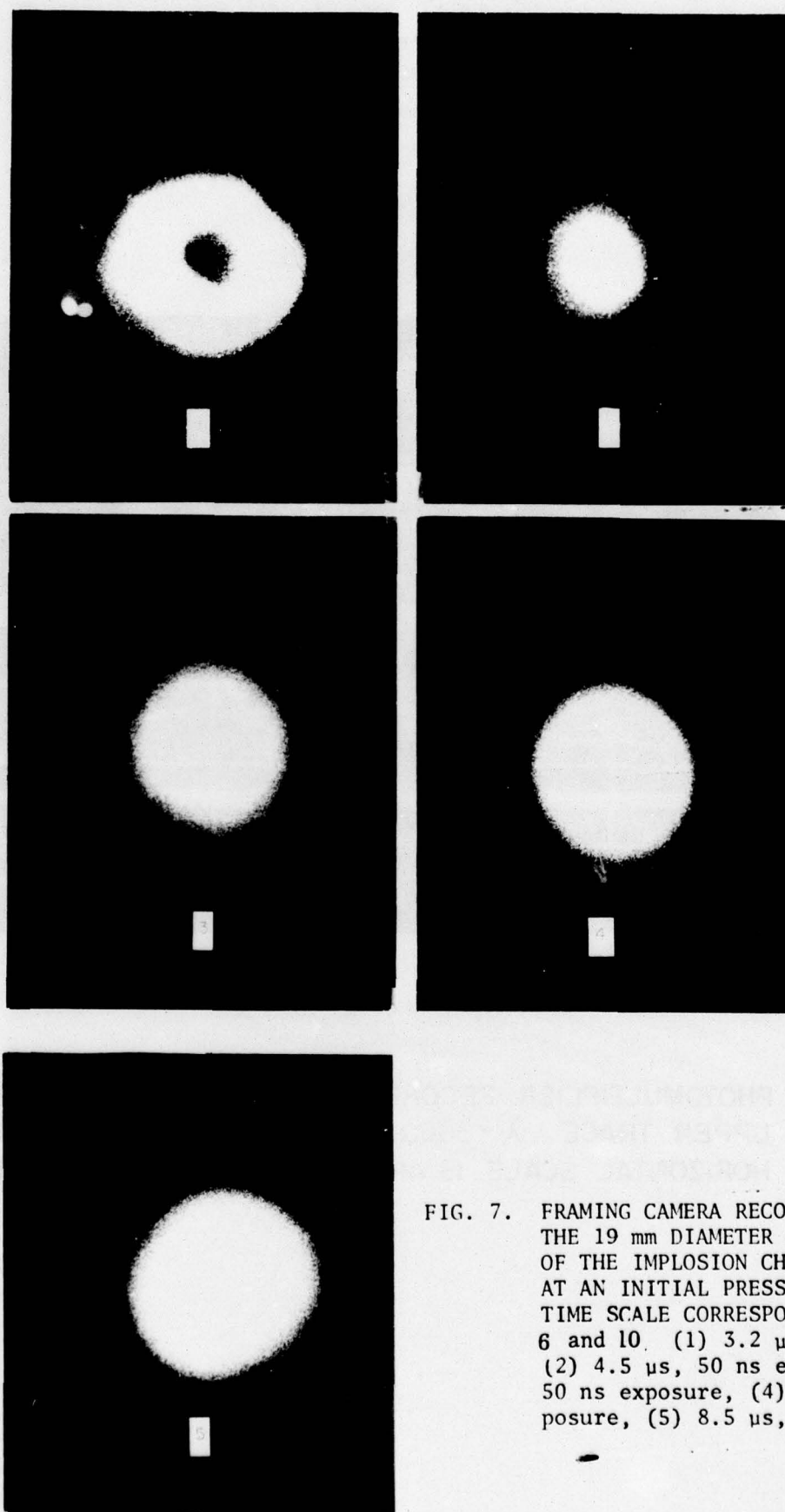


FIG. 7. FRAMING CAMERA RECORDING TAKEN THROUGH THE 19 mm DIAMETER WINDOW AT THE ORIGIN OF THE IMPLOSION CHAMBER DURING A RUN AT AN INITIAL PRESSURE OF 7 ATM. THE TIME SCALE CORRESPONDS TO THAT OF FIGS. 6 and 10. (1) 3.2  $\mu$ s, 50 ns exposure, (2) 4.5  $\mu$ s, 50 ns exposure, (3) 6.0  $\mu$ s, 50 ns exposure, (4) 7.2  $\mu$ s, 100 ns exposure, (5) 8.5  $\mu$ s, 100 ns exposure.

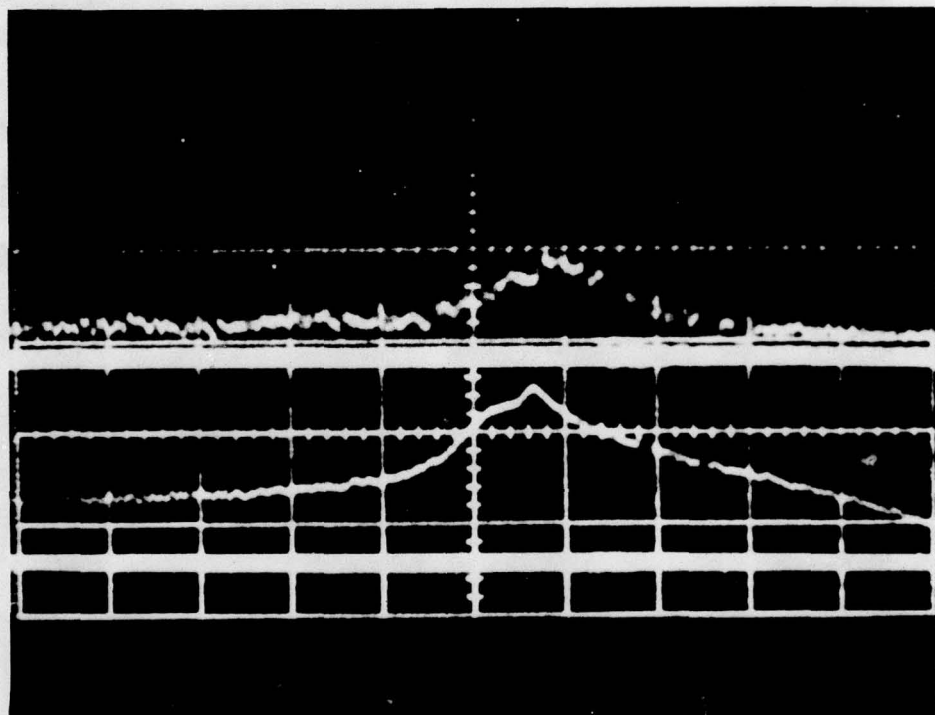


FIG. 8 PHOTOMULTIPLIER RECORDINGS OF THE FIRST IMPLOSION  
UPPER TRACE :  $\lambda = 3660 \text{ \AA}$  , LOWER TRACE :  $\lambda = 4950 \text{ \AA}$   
HORIZONTAL SCALE IS APPROXIMATELY  $2 \mu\text{s} / \text{DIVISION}$

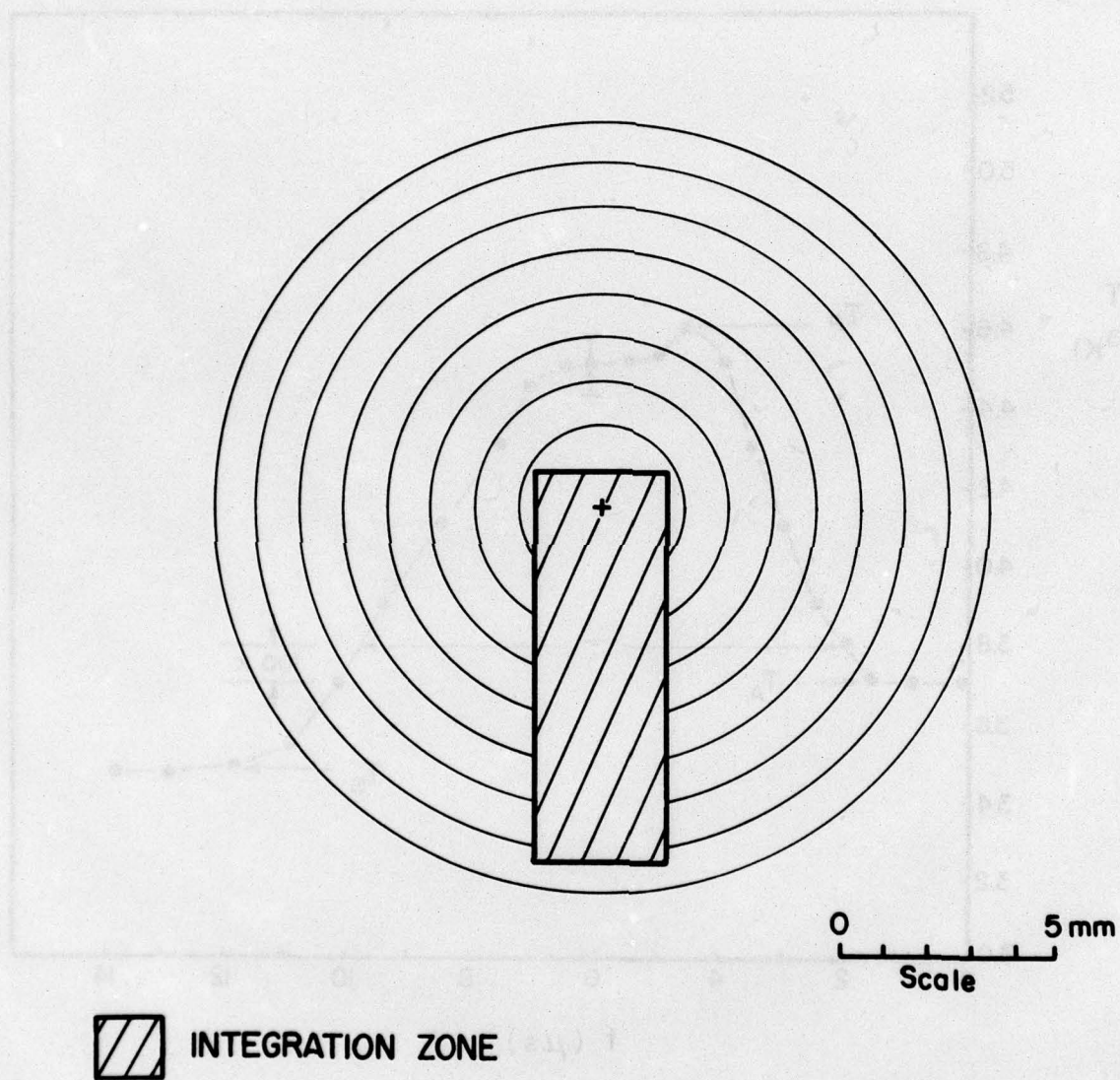


FIG. 9. PHOTOELECTRIC INTEGRATION AREA. CONCENTRIC CIRCLES SHOW ISOTHERMS FOR A PERFECTLY FOCUSED IMPLOSION.

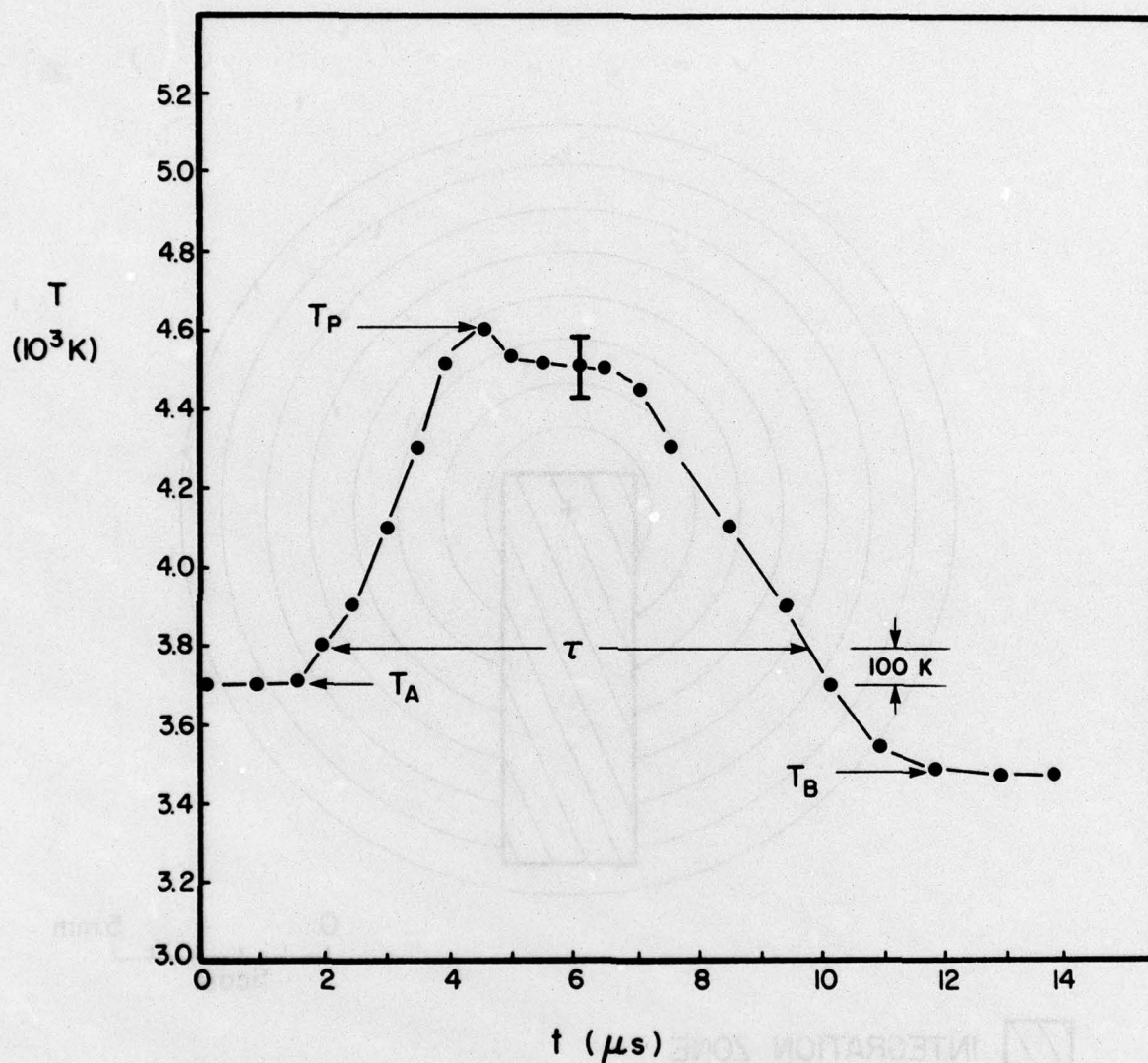


FIG. 10. TYPICAL PHOTOELECTRICALLY DETERMINED TEMPERATURE FOR AN INITIAL PRESSURE OF 7 ATM. THE AMBIENT TEMPERATURE  $T_A$  IS 3000-3500 K. AS THE IMPLOSION CONVERGES ON THE ORIGIN, THE TEMPERATURE RISES TO A PEAK  $T_P$ . FINALLY, THE PLASMA COOLS AND DISPERSES TO A TEMPERATURE  $T_B$  USUALLY ABOUT 200-400 K LOWER THAN  $T_A$ . THE IMPLOSION PULSE DURATION  $\tau$  IS DEFINED AS THE WIDTH IN TIME BETWEEN  $[T_A + 100\text{K}]$  HEIGHTS.

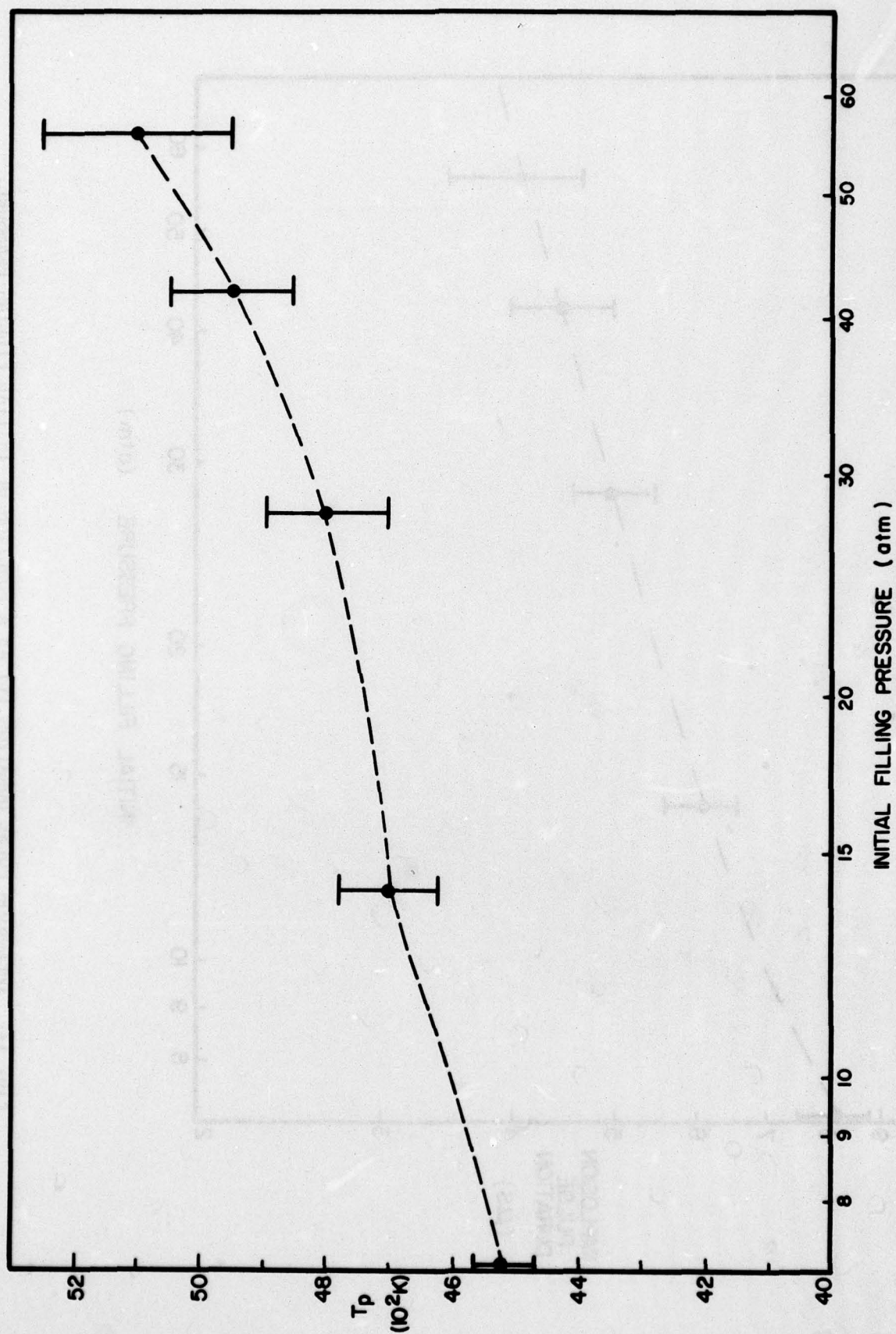


FIG. 11. PEAK TEMPERATURE ( $T_p$ ) AS A FUNCTION OF INITIAL FILLING PRESSURE

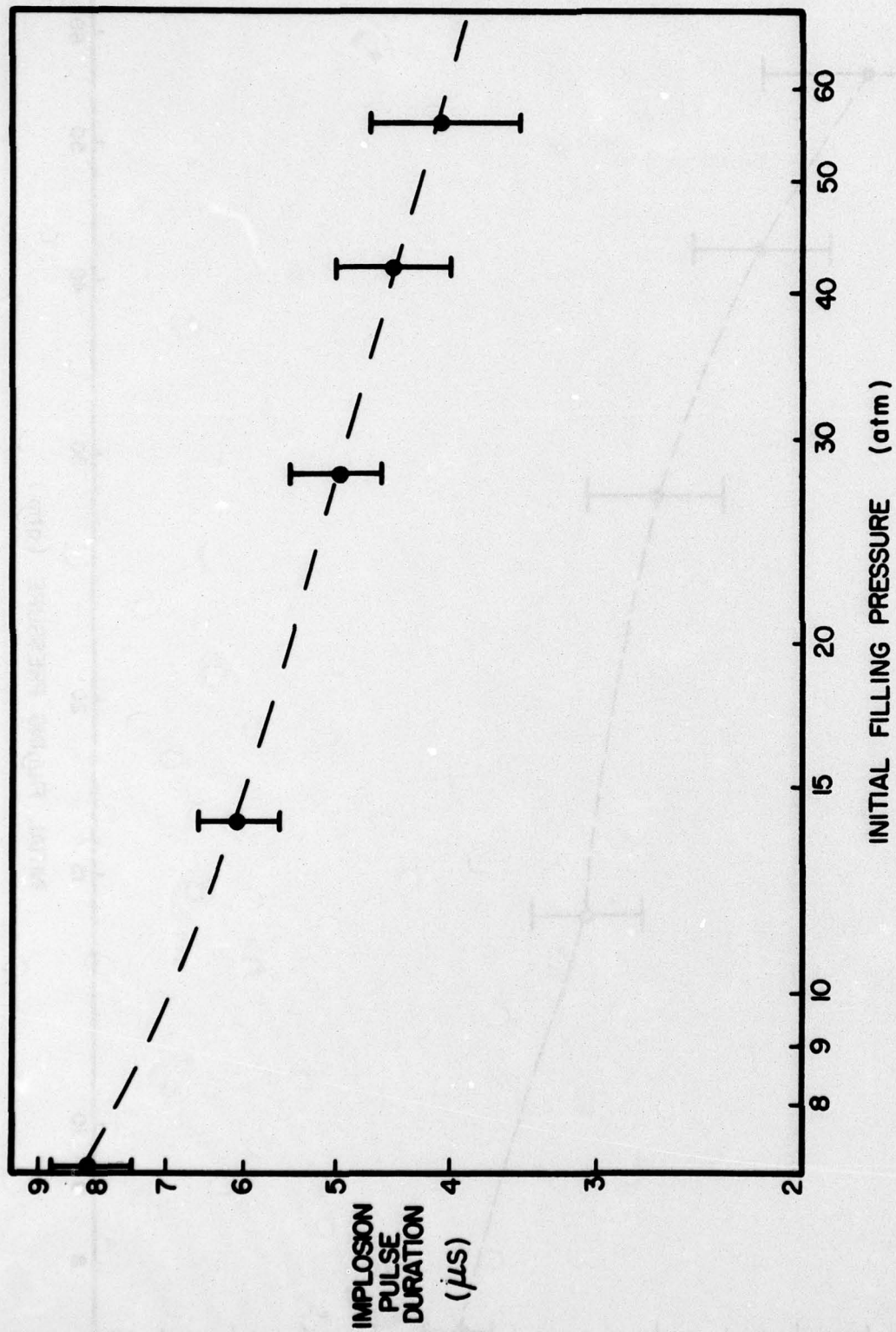


FIG. 12. IMPLOSION PULSE DURATION ( $\tau$ ) AS A FUNCTION OF INITIAL FILLING PRESSURE.

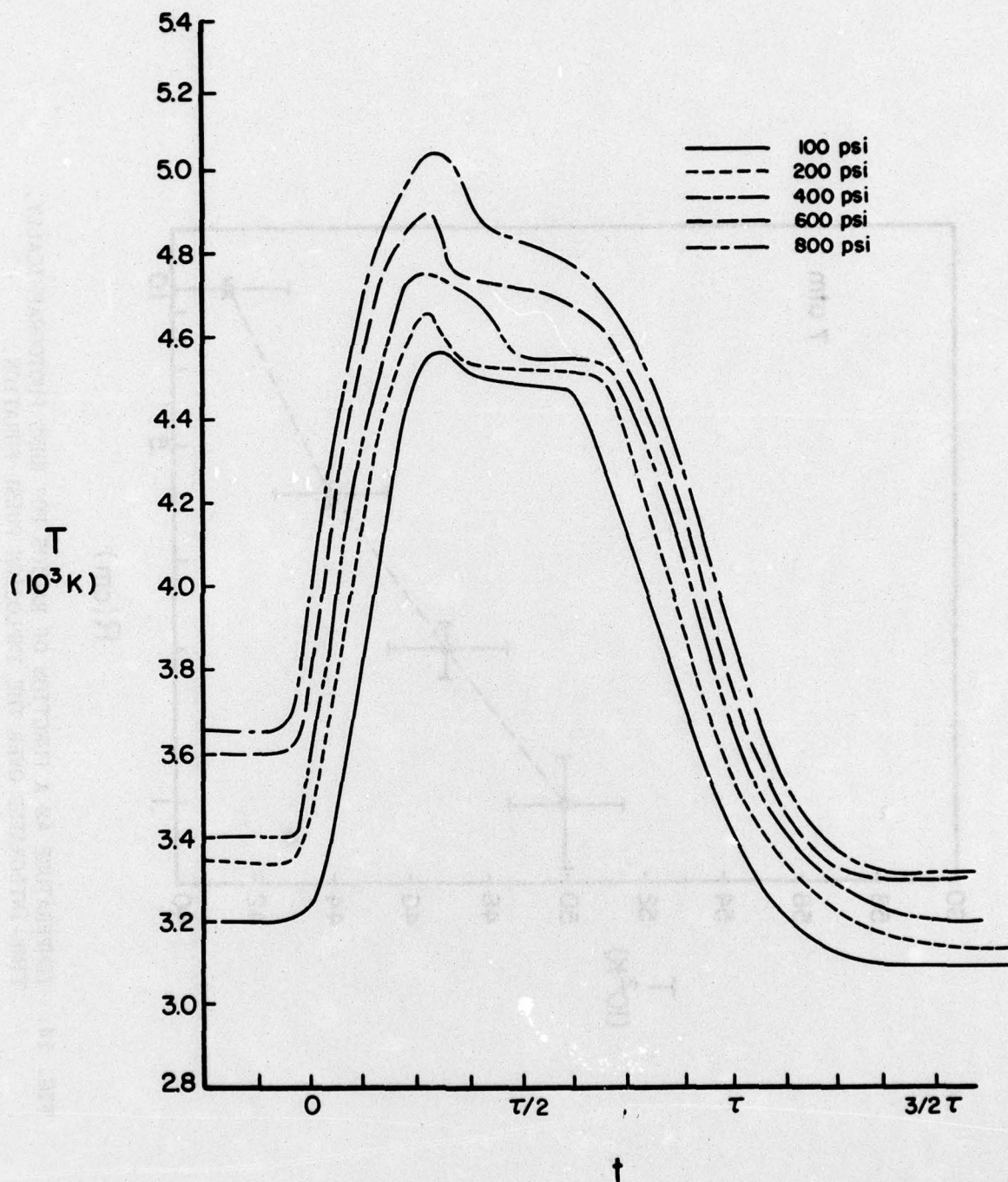


FIG. 13. "UNIVERSAL" TIME-HISTORY OF THE PHOTOELECTRICALLY DETERMINED TEMPERATURE; TIME NORMALIZED TO THE IMPLOSION PULSE DURATION.

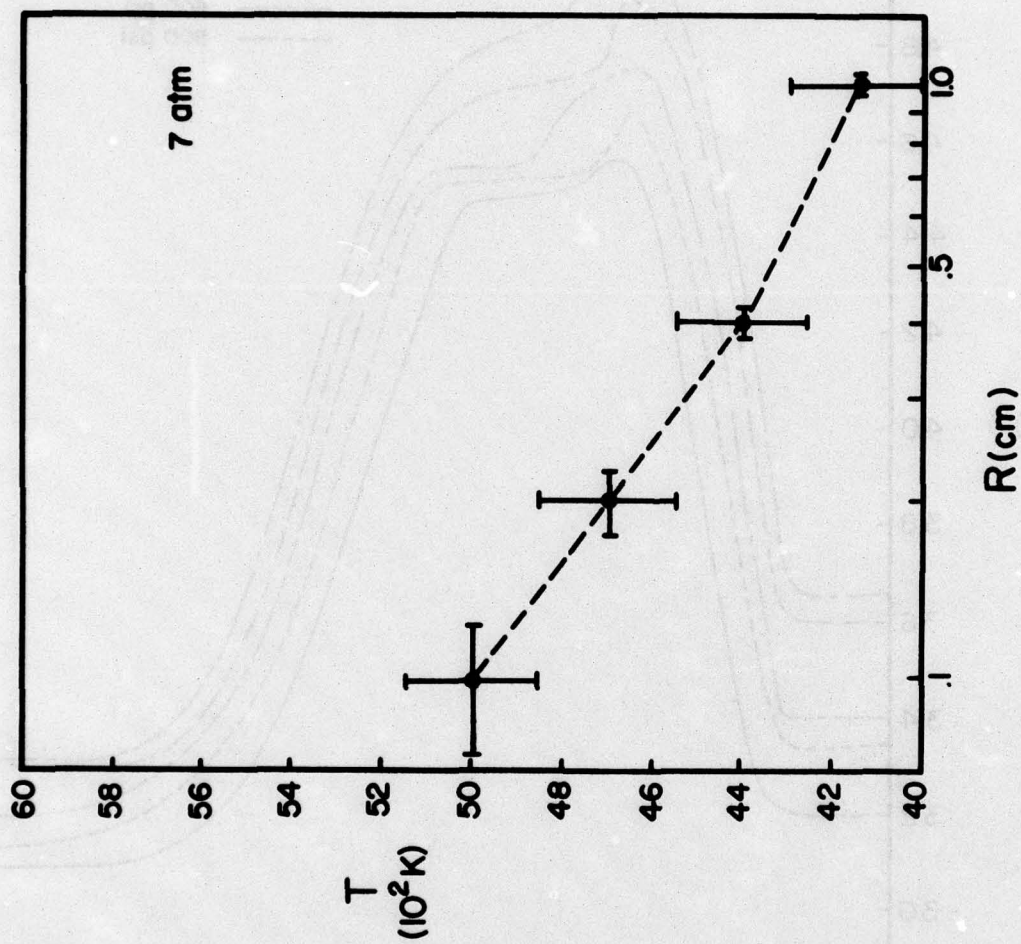


FIG. 14. TEMPERATURE AS A FUNCTION OF RADIUS FOR RUNS PHOTOGRAPHICALLY, TIME-INTEGRATED OVER THE IMPLOSION PULSE DURATION.

(a) 7 ATM INITIAL PRESSURE

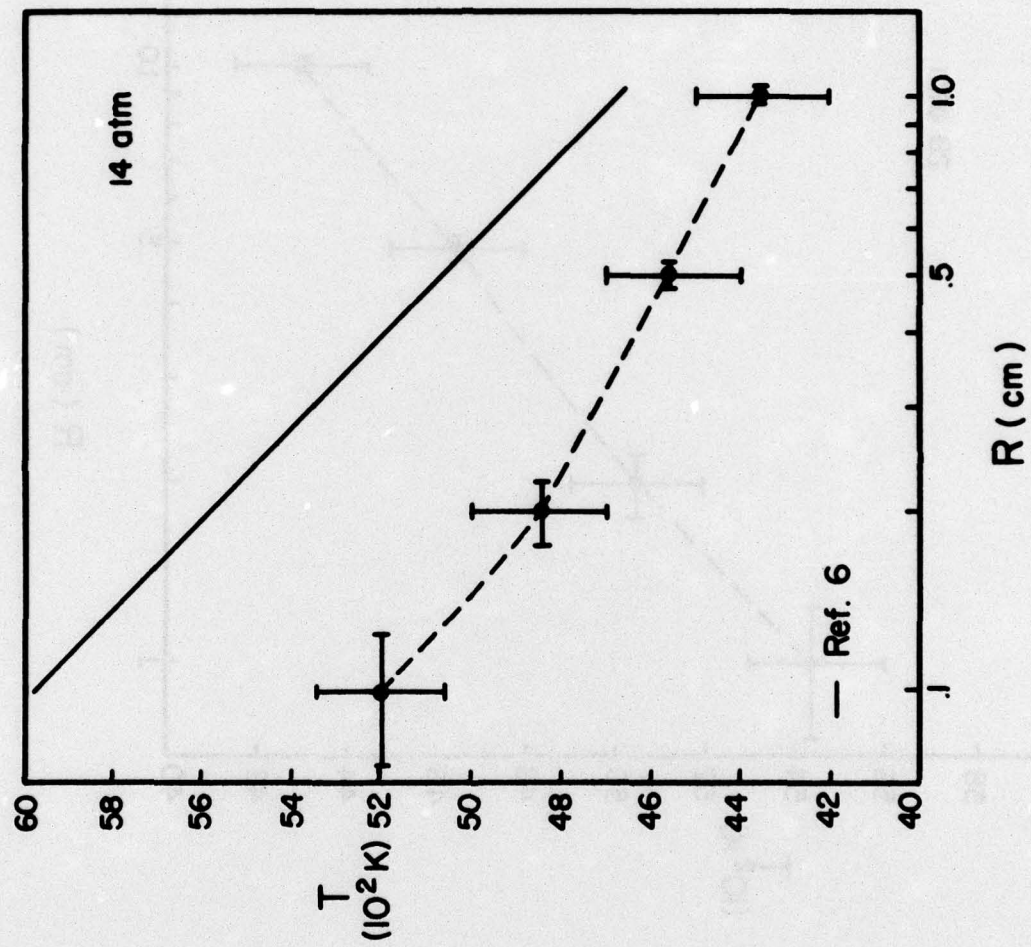


FIG. 14

(b) 14 ATM INITIAL PRESSURE

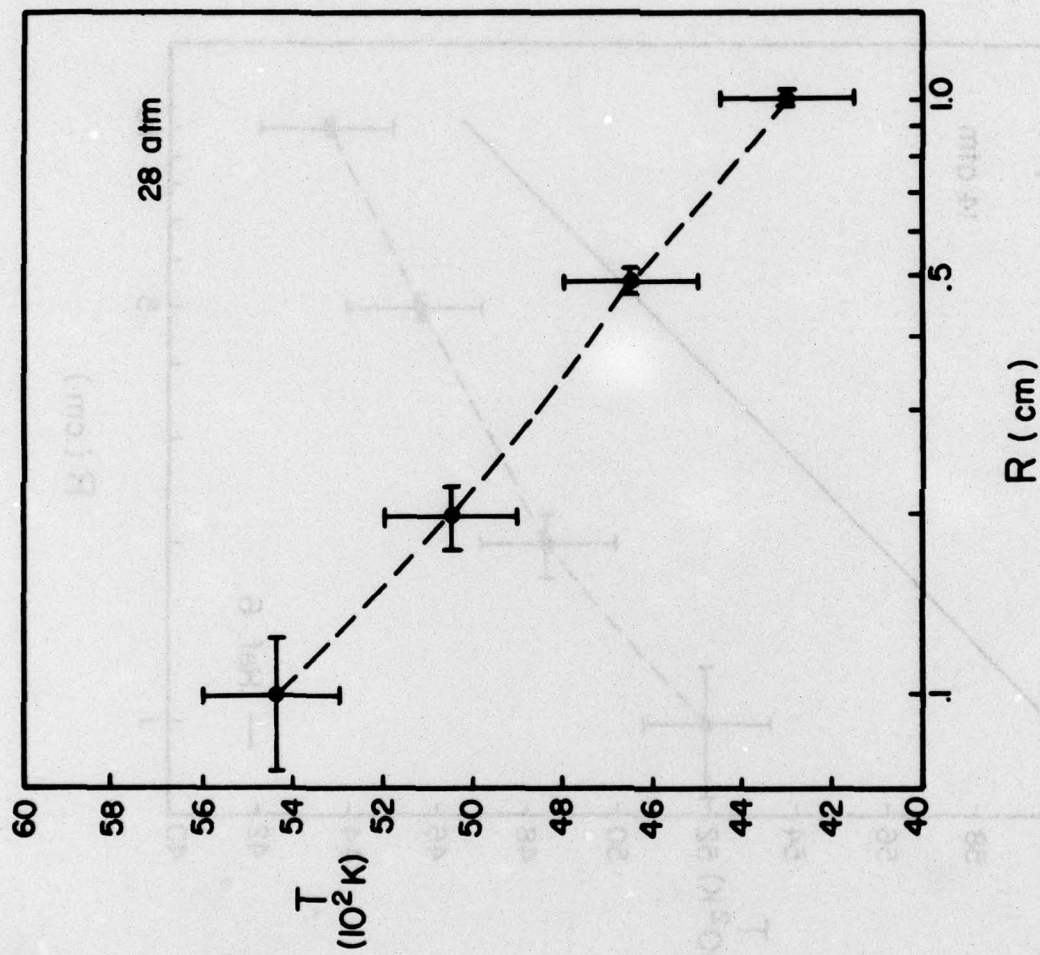


FIG. 14 (c) 28 ATM INITIAL PRESSURE

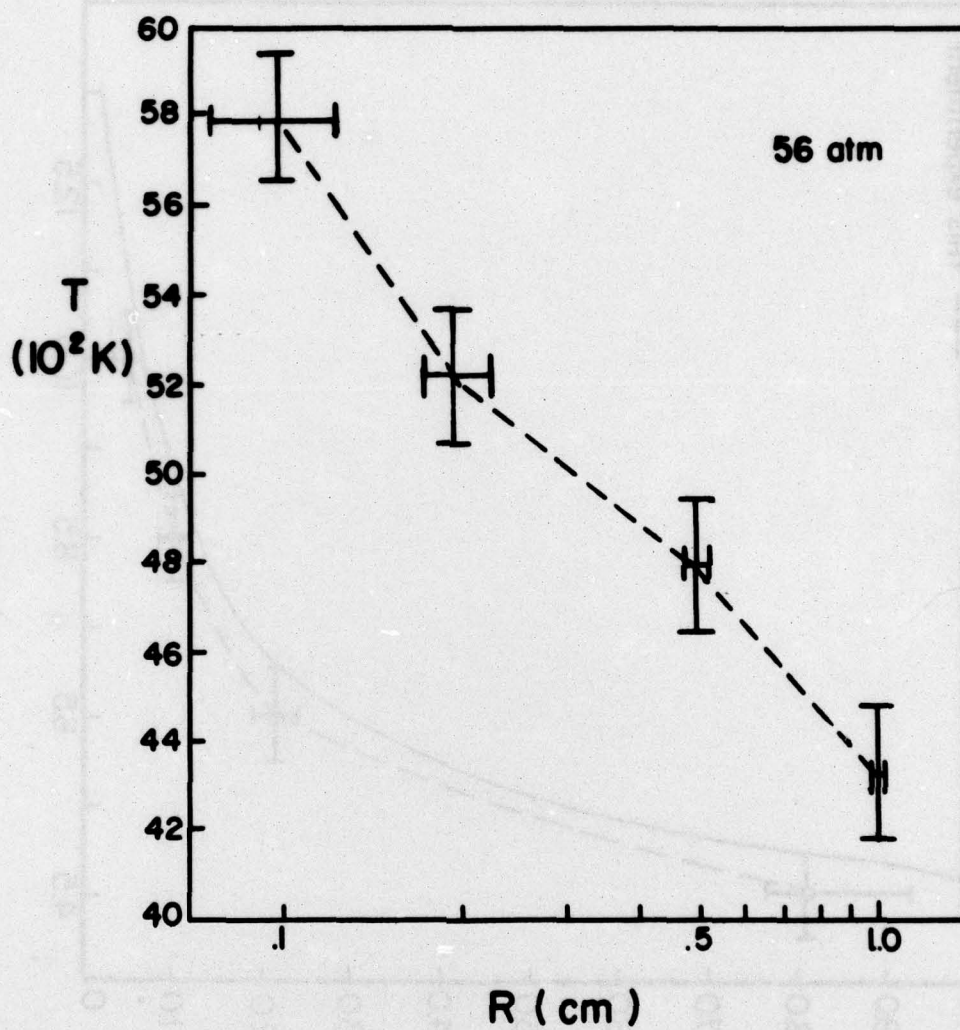


FIG. 14 (d) 56 ATM INITIAL PRESSURE

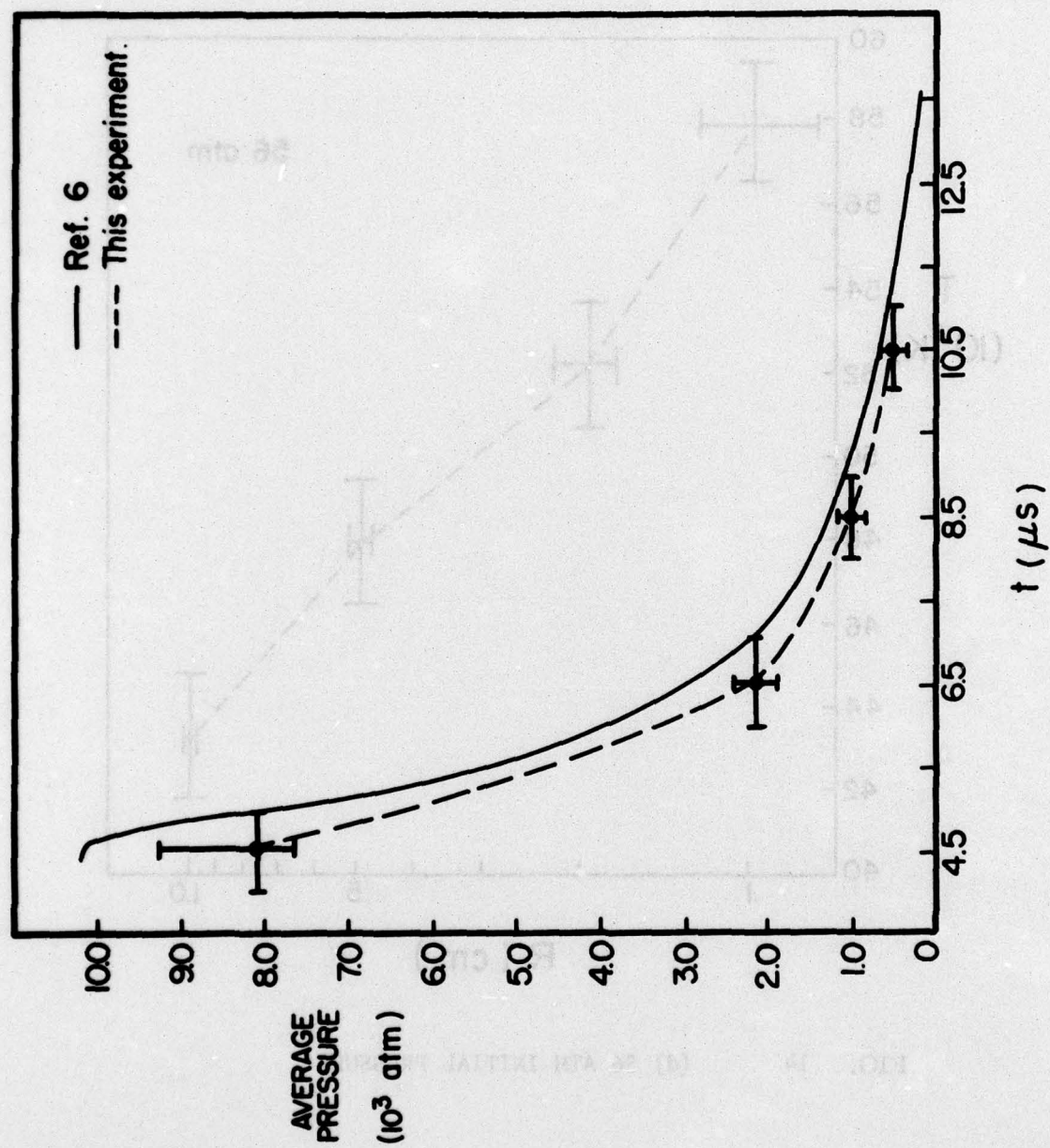


FIG. 15. ESTIMATED PEAK PRESSURE AND DECAY CURVE FOR A 7 ATM INITIAL PRESSURE EXPERIMENT.

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Rodg, Randy A. 31 pages 18 figures

1. Implusions
2. Spectroscopic temperatures at implusion focus
3. Piezo pressures at implusion focus

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) Time and spatially-resolved spectroscopic studies have been made of imploding shock waves in a 20-cm diameter hemispherical chamber filled with $2H_2+O_2$ mixtures at high initial pressures (7-56 atm). Changes in the initiation system (an exploding wire) have improved the precision of the focus and the reproducibility of the implosion pulse. By using the blackbody character of the plasma radiation above 3000Å, the temperature structure of the implosion was determined both temporally and spatially as a function of initial filling pressure. It was found that peak temperatures (4500-5100K), averaged over a rectangular area		

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3 mm x 9 mm centered near the origin, increased monotonically as a function of filling pressure, while implosion pulse duration (8.5-4.0  $\mu$ s) underwent a monotonic decrease. The implosion pulse, normalized by the duration and temperature rise, appeared to have a nearly universal shape. The spatial gradient of temperature  $[dt/d(\log R)]$ , averaged over the implosion pulse duration, increased monotonically as a function of initial filling pressure. All temperature results (peak temperature, duration, and gradient) averaged 15-20% below theoretical predictions. The time history of the pressure at the origin for an initial filling pressure of 7 atm, averaged over a 6.3 mm diameter circle, was measured by using a high-pressure piezoelectric transducer. The peak pressure, about 8 kbar, is 15-20% below theoretical predictions. This result represents the first direct measurement of pressure achieved at the focus of a gas-driven hemispherical implosion. To check the effect of window conduction upon the plasma located at the focus, the window was recessed 3 mm from the geometric center of the hemisphere. No change in peak temperature was observed, although as might be expected from the change in position of the reflecting surface, the implosion pulse duration decreased by 18%. The presence of debris (such as that left by the exploding wire) was found to lower both the implosion pulse duration and the temperature remaining after the implosion. No effect on peak temperature was measured, even when the effect was enhanced by the addition of an easily vaporized impurity (silicon grease).

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